Educational Note

UNDERSTANDING EMI PRECOMPLIANCE TESTING

Paul Denisowski | Version 01 | 01.2023

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Contents

1 Introduction

The expansion of electronic and radio frequency technology into almost every aspect of daily life has greatly increased the importance of electromagnetic compatibility (EMC) testing. This educational note discusses the fundamentals of EMC precompliance testing: what precompliance is, why precompliance is important, and how precompliance testing is performed.

2 About compliance testing

2.1 General

Regardless of their intended purpose or function, most modern electrical and electronic devices must meet two requirements.

The first of these requirements is that devices should not emit excessive levels of unintentional and undesired radio frequency (RF) energy, since this energy has the potential to interfere with the proper functioning of other nearby devices. This requirement is commonly referred to as **electromagnetic interference** (EMI) and is the focus of this educational note.

The second requirement is that the device itself should be relatively immune to radio frequency signals. In other words, the device should still function properly when exposed to (high) levels of radio frequency energy. This is called **electromagnetic susceptibility** (EMS).

With regard to EMI, devices must be tested to show that they **comply** to various standards, such as CISPR or MIL-STD. These standards are specified by the responsible regulatory agency, such as CE (in Europe) or the FCC (in the United States). The required compliance tests must be passed before selling, or even advertising or marketing, a product.

Figure 1 - EMC compliance test

There are hundreds of different EMC related standards, and the relevant standard(s) are often determined based on criteria such as the country or region where the device will be used or the expected use environment: a device intended for use in the home will normally need to conform to different requirements than a device intended for industrial or military applications.

It is very important to remember that EMC testing is primarily concerned with testing for **compliance** to these various standards.

2.2 Conducted and radiated testing

Compliance testing can be divided into two main categories: conducted and radiated.

In **conducted** testing, measurements are made of the signals that the equipment under test (EUT) introduces onto the AC power or “mains” network, most often through the EUT's power cord. Because this type of testing is concerned with conducted signals, the measured frequency range is relatively low, typically

9 kHz to 30 MHz. In order to measure these conducted signals, the EUT is normally plugged into special device called a line impedance stabilization network (LISN), and the LISN is then connected to the measuring instrument. LISNs are discussed in more detail in section 6.1.

The other type of EMC compliance testing is **radiated** testing, in which measurements are made of the signals radiated by the device under test. Radiated testing is usually performed from 30 MHz to 1 GHz, although some standards require testing at much higher frequencies. Since these tests involve measuring radiated signals, one or more antennas are required, and these antennas are then connected to the measuring instrument. Radiated compliance testing also normally requires a shielded chamber or suitable open air test site. This reduces the risk of inaccurate EMI test results due to unrelated ambient signals as well as minimizes the possibility of EMS tests causing interference outside of the testing area,

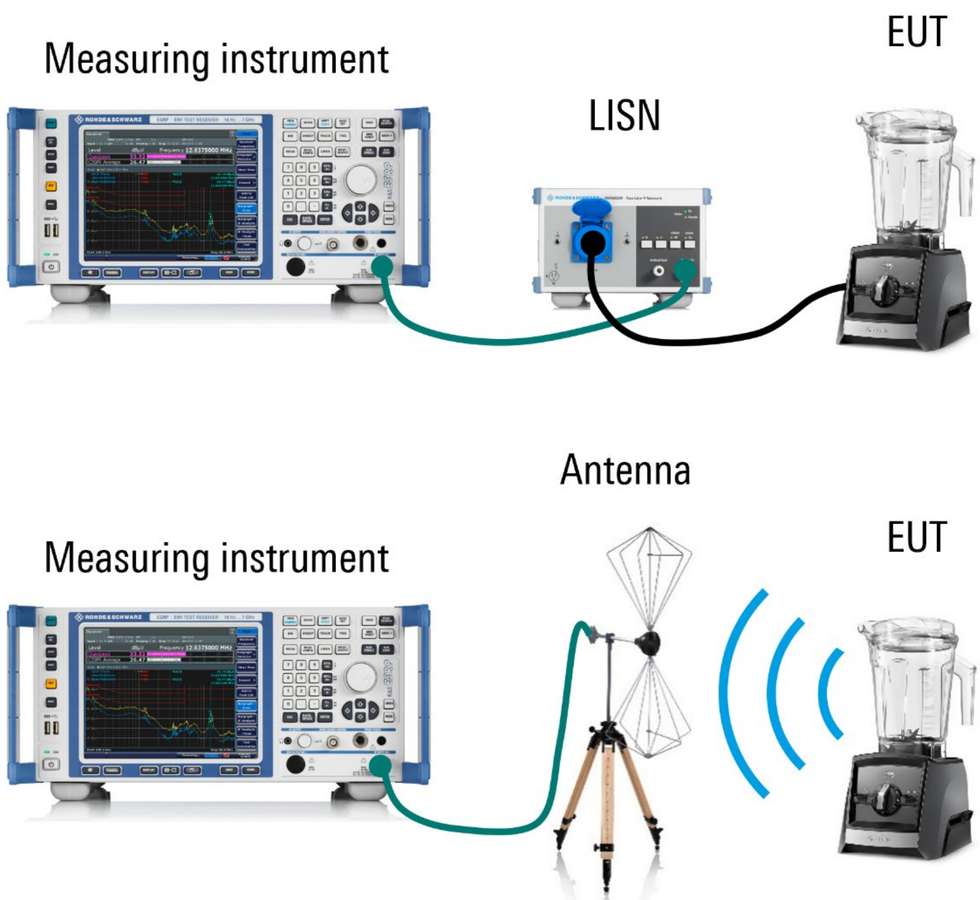

Figure 2 - Conducted (top) and radiated (bottom) testing

2.3 About compliance testing

In the case of both conducted and radiated emissions, compliance testing is almost always performed by a certified third-party test lab or test house, not by the manufacturers themselves. These compliance test labs follow strict and precise procedures defined in the standards, and this in turn requires specialized equipment, special facilities (e.g. anechoic chambers), as well as trained testing personnel. As one might expect, compliance testing can be very expensive: typically the testing fee is thousands or tens of thousands of US dollars per attempt.

Unfortunately, failing compliance testing is not uncommon. Depending on the type of testing and the standards involved, the failure rate can be in the range of 70 to 90 percent. If any portion of the test is failed, the entire test is considered unsuccessful, and the device manufacturer must then schedule a new test and pay the testing fee again. Any necessary product redesign or remediation must be performed before retesting, and this requires additional time and money as well.

One universal truth in EMC testing is that problems can be fixed more easily, more cheaply, and more quickly the earlier they are discovered in the design cycle. Testing a product for EMC related issues before formal compliance testing is referred to as a **precompliance** testing.

2.4 About precompliance testing

EMI precompliance testing is performed by the device manufactures, in their own labs and with their own equipment. The goal of precompliance testing is to discover potential issues earlier in the design cycle, thus increasing the probability of passing the formal compliance tests.

Formal compliance testing only yields “pass-fail” results and does not provide much insight into the causes for the failure. Precompliance testing, on the other hand, can be stopped at any time and the reasons for issues can be thoroughly analyzed, tested and debugged.

Figure 3 illustrates the EMC testing process. As mentioned above, EMI debugging and analysis should be incorporated into the design process itself. If initial measurements do not reveal any serious issues, the EUT moves into precompliance testing. In precompliance, the goal is to test the EUT in a way that most closely approximates the required compliance tests. If any of these precompliance tests are failed, the EUT moves back into the design / debugging phase, where any necessary changes can be made. Once precompliance tests have been successfully passed, the EUT then moves into full compliance testing at a lab or test house. Successfully passing the required compliance tests results in formal certification, allowing the device to be marketed and sold. If, however, the EUT fails any of the formal compliance tests, it moves back into precompliance testing and/or debugging to resolve any outstanding issues..

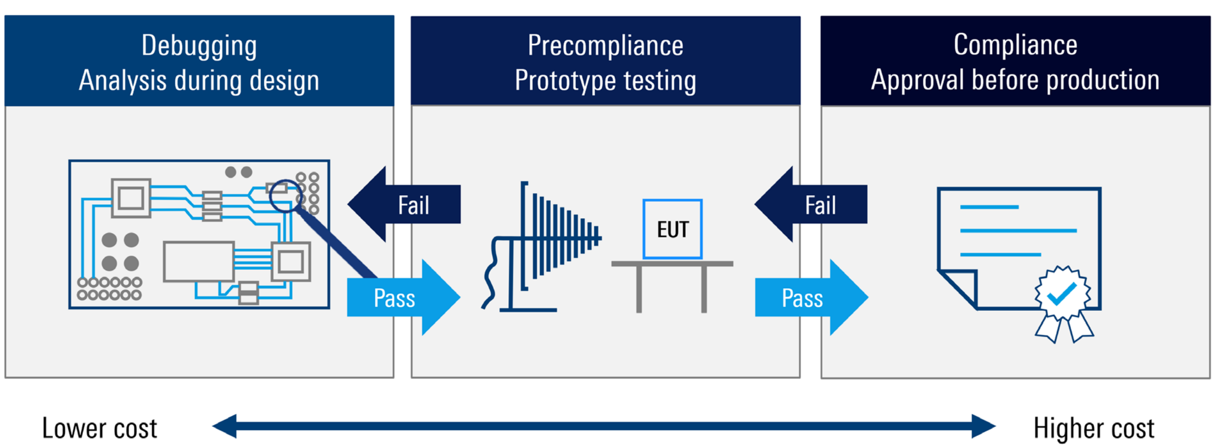

Figure 3 - EMC testing process

3 Considerations in precompliance testing

There are two main considerations involved in precompliance testing. The first is determining where the precompliance tests will be performed. This may be in a shielded or anechoic chamber, indoors, or at an outdoor test site. The second major consideration is the choice of instruments and accessories used to perform the precompliance tests. The remainder of this educational note will discuss both of these considerations in detail and will explain any differences between compliance testing and precompliance testing.

4 Test location and site

Formal compliance testing normally requires that tests be performed in specific test environments or using specific test setups. In the case of conducted testing, the testing environment is relatively easy to set up: in addition to the test instruments and accessories, usually all that is required is a simple ground plane and non-conductive table. Therefore, conducted precompliance testing is often almost identical to full compliance testing.

On the other hand, radiated compliance testing generally requires a shielded chamber or a suitable open air test site. Due to the size, cost, and complexity of configuring these types of facilities, most radiated precompliance testing cannot precisely duplicate the compliance testing environment.

As a result, modifications are often made when performing radiated precompliance tests, such as adding margins to the measurement results. For example, if a smaller chamber were used, measured emissions would be stronger because of the reduced distance between the antenna and EUT. In this case, emission limits would need to be raised to account for the stronger signals. Going from a typical compliance distance of 10 meters to a typical precompliance distance of 3 meters, as shown in Figure 4, might require raising emission limits by approximately 10 dB.

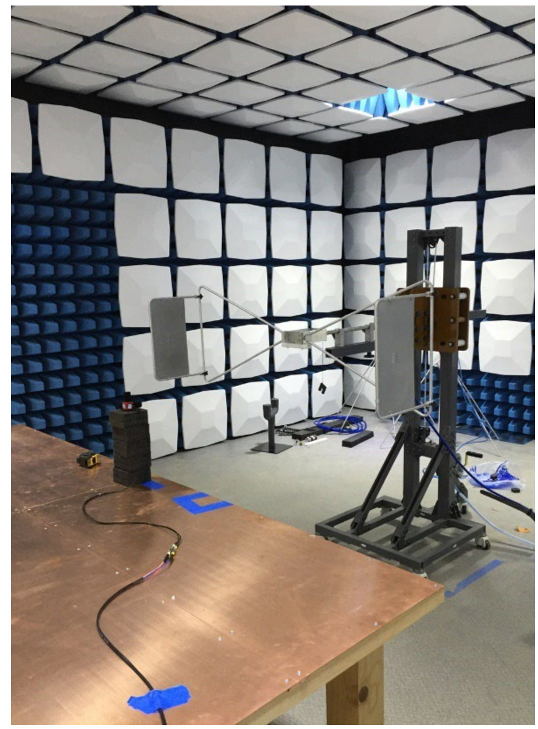
Figure 4 - Radiated precompliance test (note distance between EUT and antenna)

5 Instruments used in precompliance

There are two main categories of instruments used in precompliance testing. **Spectrum analyzers** and/or **EMI receivers** are most commonly used to **measure** emission limits, whereas oscilloscopes are primarily used for **debug** and/or **troubleshooting**.

5.1 EMI receivers and spectrum analyzers

Both EMI receivers and spectrum analyzers (Figure 5) are frequency domain instruments, that is, they measure and display power as a function of frequency. Frequency domain analysis is essential for EMI testing since conducted or radiated power levels are measured over a range of frequencies defined by a standard. A "passing” result occurs when all measured values fall below a defined power-versus-frequency limit line (discussed below).

Although it's possible to perform measurements at individual frequencies and compare the results to the specified limits point by point, spectrum analyzers and EMI receivers use automated routines that step through or scan the frequency range of interest. This functionality may be built-in to the instrument itself, and/or be implemented in external software.

There are however some differences between EMI receivers and spectrum analyzers. Some EMI testing features can be found on both instruments, such as **limit lines** and **spectrograms**. Other features are only found on EMI receivers. Two important functions that are only available on EMI receivers are **time domain scanning** and **preselection**.

Figure 5 - EMI receiver and spectrum analyzer

5.1.1 Limit lines

Limit lines are a basic but vitally important feature on both EMI receivers and spectrum analyzers. Recall that compliance testing involves measuring power levels at different frequencies in order to determine whether conducted or radiated levels are below the specified limit over a range of frequencies. These maximum power values or limits are defined in terms of **limit lines**, which can either be configured directly on and/or loaded into the measuring instrument.

For example, in Figure 6 a limit line has been loaded into a spectrum analyzer or EMI receiver before making measurements. A fail result occurred where the measured power exceeded the limit line. Measurements of power versus frequency are often made using different detector types, such as peak, quasi-peak, and average (discussed below), and in this case, limit lines are defined for the specific detector types used. In Figure 6, the peak limit line was violated by the blue peak detector trace but the quasi-peak limit line was not violated by the green quasi-peak detector trace.

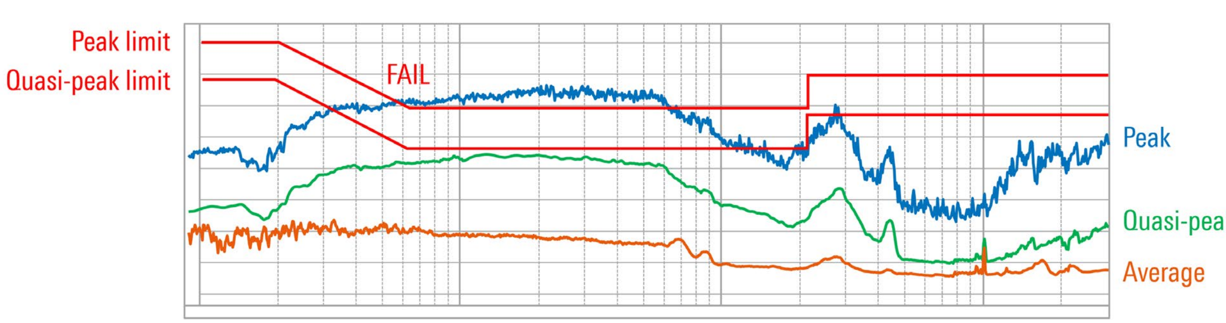

Figure 6 - Limit lines and traces

5.1.2 Detector types

For both EMI receivers and spectrum analyzers, **detectors** determine how measurements made during a time interval are combined into a single value. For example, in Figure 7 the measured signal is pulsing over time. If results were calculated over the indicated intervals, the resulting values for each interval would depend on the detector type. For the **peak** detector, the maximum value in each interval is chosen. The **quasi-peak** detector, on the other hand, measures the "annoyance" of a signal using a type of charging and discharging behavior. And the **average** detector simply yields the average value over each interval. The effect of different detector types can be clearly seen in the different traces in Figure 6.

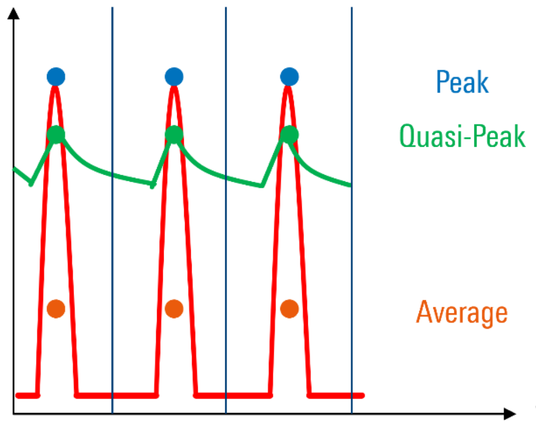

Figure 7 - Common detector types

Compliance measurements often use the quasi-peak detector, but the peak detector is more common in precompliance testing. There are two main reasons for this. First, measurements made with the peak detector are always much faster than the quasi-peak, usually by at least several orders of magnitude. Additionally, peak detector results are always higher than quasi-peak results. This means that if a test passes precompliance testing using the (faster) peak detector, it will also pass using the (slower) quasi-peak detector.

5.1.3 Spectrograms

Another common feature used in EMI precompliance testing is spectrograms. A spectrogram is a plot of power versus frequency versus time. In order to display these three quantities in only two dimensions, signal power or intensity is mapped to the visible color spectrum: red indicates maximum power and purple or violet indicates minimum power.

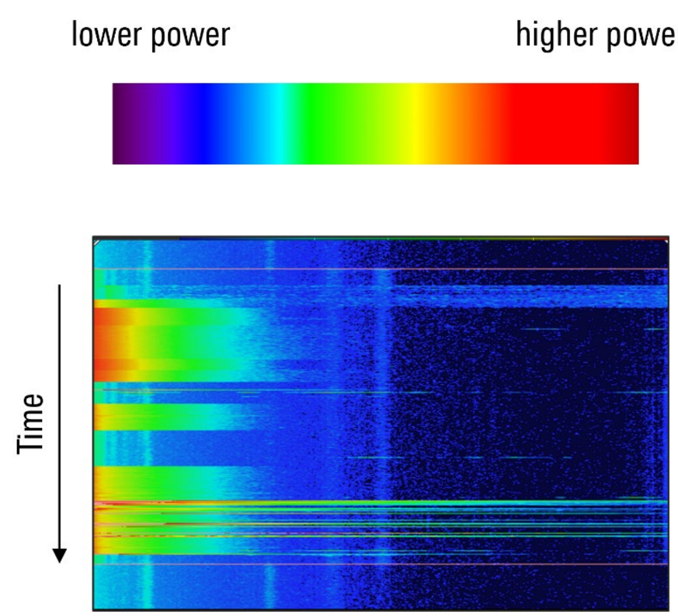

Figure 8 - Spectrogram

Spectrograms are sometimes referred to as "waterfall" diagrams because they are drawn from top to bottom. The most recent measurements appear in the top line of the display and then "flow" downwards.

Spectrograms are useful because they show how signals change over time and over a range of frequencies. This enables easy identification of time-varying signal behavior such as drifting, frequency hopping, etc. Spectrograms also make it easier to see smaller signals in the presence of larger signals. Most spectrum analyzers and EMI receivers have spectrograms as a standard feature, and spectrograms are also common on oscilloscopes when displaying frequency-domain information in so-called FFT mode (discussed in section 5.2).

5.1.4 Preselection

Preselection is an important differentiator between EMI receivers and spectrum analyzers. Spectrum analyzers are most often used to measure signals that are being generated or controlled by the user. In EMI testing, however, the input signal is neither known nor controllable. It is therefore possible that out-of-band or “off-screen” signals could overload the measuring instrument's first mixer and cause compression or distortion, leading to invalid or misleading measurement results.

Preselection is a method used in EMI receivers to protect the first mixer. It is implemented as a switchable bank of filters that allows the receiver to select only the frequencies of interest. The particular filter is chosen automatically by the receiver based on the configured input frequency.

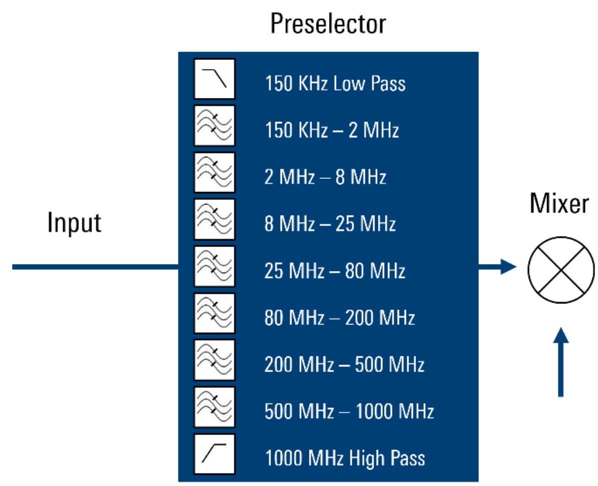

Figure 9 - Preselection in EMI receivers

Many EMI standards require the “measuring instrument” to have preselection, and this is why compliance testing is performed using EMI receivers rather than spectrum analyzers. Note that although many spectrum analyzers have something called “preselection,“ this usually refers to high-pass filtering based on YIG technology rather than the switchable filter bank form of preselection found in EMI receivers.

5.1.5 Time domain scan

Another feature only found on EMI receivers is time domain scan. Traditionally, EMI receivers made measurements using a stepped frequency scan with a small resolution bandwidth. This method of measuring is very accurate, but it can also be very slow, especially for the wide spectral ranges found in radiated emissions measurements.

More modern EMI receivers are able to overcome this limitation by using time domain scan, in which the measurement range is split into very large blocks of spectrum, each of which is then digitized and processed using the fast Fourier transform (FFT). Time domain scan provides a very significant speed improvement over the traditional stepped scan, and this is accomplished without a reduction in measurement accuracy. Time domain scan has been approved for use in most types of compliance testing, and therefore it is also often used to reduce precompliance testing test time as well.

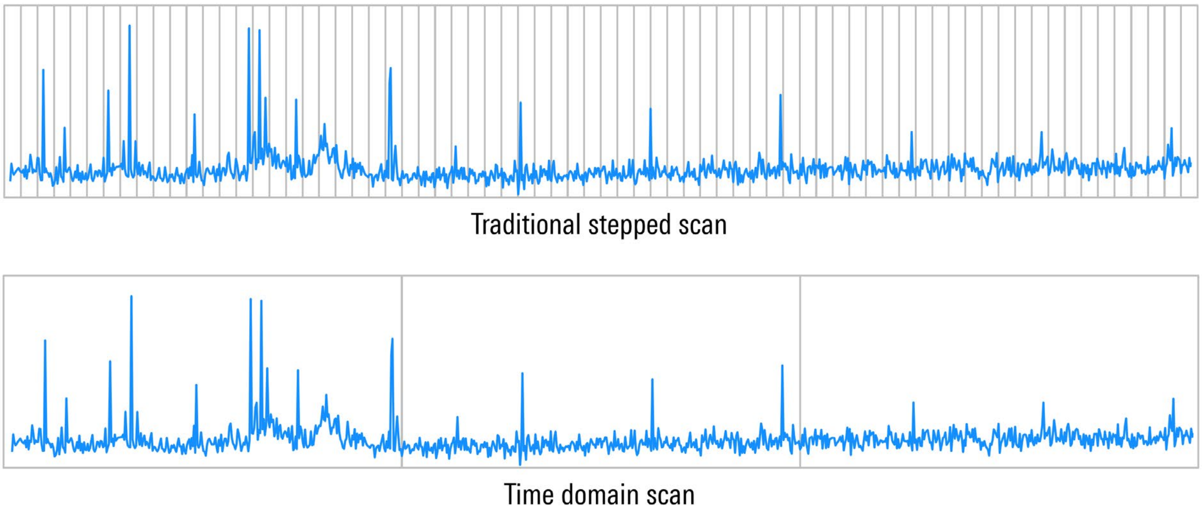

Figure 10 - Stepped scan and time domain scan

5.2 Oscilloscopes

Unlike spectrum analyzers or EMI receivers, oscilloscopes are primarily to make **time domain measurements**, that is, measurements of voltage as a function of time. Oscilloscopes are a vital tool in electrical and electronic design and this makes them invaluable when attempting to locate, debug, or remediate sources of non-complying emissions.

Figure 11 - Oscilloscope

As will be discussed in the next section, many modern oscilloscopes also have the ability to make frequency domain measurements, enabling them to be used in a similar way to spectrum analyzers or EMI receivers. An additional benefits of oscilloscopes is that modern oscilloscopes generally have wide bandwidth. Like EMI receivers and spectrum analyzers, oscilloscopes can be used to examine both conducted and radiated signals.

One potential drawback of using oscilloscopes for precompliance testing is that they usually do not natively support limit lines, although limit lines and other EMI-related features can sometimes be implemented using an external software program that obtains and processes data from the oscilloscope.

5.2.1 Fast Fourier Transform

Although they are primarily time-domain instruments, oscilloscopes can be used to display and analyze frequency domain data by performing a fast Fourier transform (FFT) on the acquired time domain data. The result is similar to what is seen on a spectrum analyzer or EMI receiver, that is, a display of power versus frequency. One important advantage of using an oscilloscopes for precompliance testing is that some oscilloscopes allow the time and frequency domain data to be viewed simultaneously. This in turn allows events in one domain to be correlated with events in another domain, which is extremely helpful when debugging EMI issues. For example, in addition to the traditional time-domain trigger found in oscilloscopes, a frequency domain trigger may also be supported. This trigger occurs when a frequency mask, or region is violated, as shown in Figure 12. Once the oscilloscope has been triggered by this frequency domain event, the related or underlying time-domain event can then be analyzed to determine the root cause of the violation.

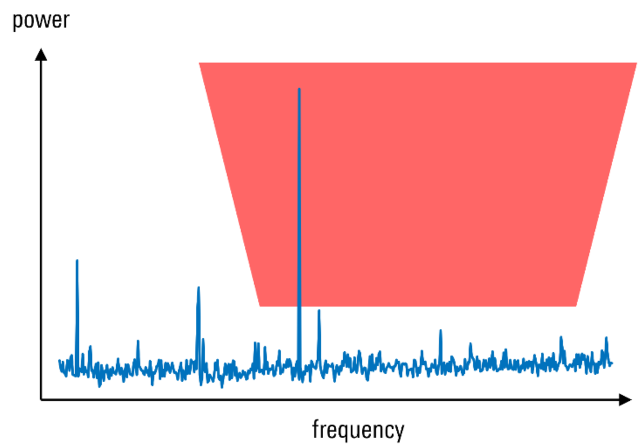

Figure 12 - Frequency mask trigger

5.3 Summary: instruments used in precompliance testing

Figure 13 provides a brief summary and comparison of the instruments used for precompliance testing. EMI receivers are unlike both spectrum analyzers and oscilloscopes in that they support both preselection as well as time domain scan. Features such as spectrograms and limit lines are generally supported by all three instruments, although external software may be required for limit line testing using an oscilloscope.

It is important to keep in mind that EMI receivers tend to be specialized instruments compared to the more general purpose spectrum analyzers and oscilloscopes. However, EMI receivers are also the instruments used for full compliance testing, so using them for precompliance leads to closer correlation with compliance testing results. Finally, wide bandwidth and the ability to correlate time and frequency domain data make oscilloscopes very valuable for debugging issues discovered during precompliance testing.

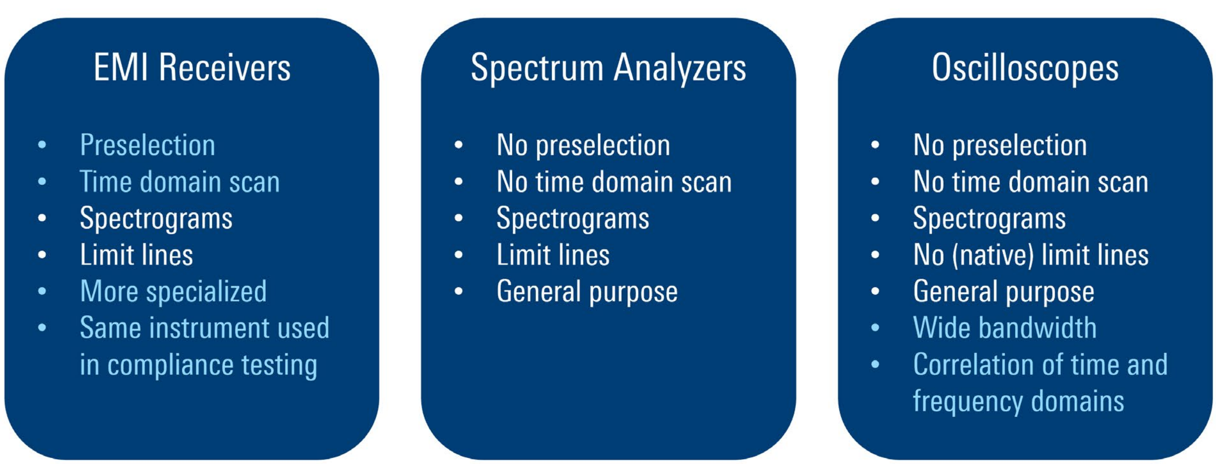

Figure 13 - Summary and comparison of instruments

6 Accessories used in precompliance

In addition to the different types of instruments that can be used for precompliance, there are a number of different tools or accessories that are commonly used when making precompliance measurements. These are LISNs, antennas, near field probes, and software.

6.1 LISN

As mentioned in section 2.2, a LISN (line impedance stabilization network), is used in conducted emissions testing. LISNs are also sometimes referred to as "artificial mains networks" or "V networks." As the name implies, one of the main functions of a LISN is to provide a stable impedance on the AC mains (line) end of the EUT's power cord. Since power outlet impedance can vary widely, a LISN ensures consistent, repeatable results regardless of where the test is conducted.

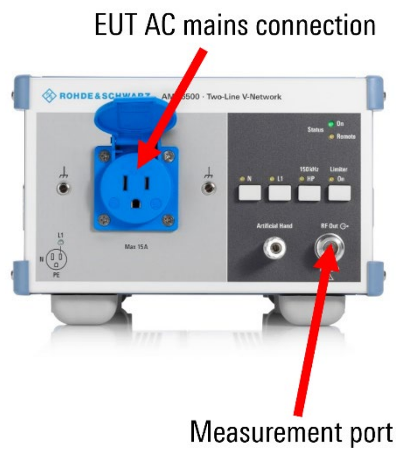

Figure 14 - LISN and connections

Another important function of a LISN is blocking any RF signals present on the AC mains from entering the EUT via the EUT's power cord. This ensures that any measured emissions are coming from the EUT rather than being conducted in from the AC mains network. As shown in Figure 14, a LISN is very easy to use: the EUT is plugged into the mains connection port of the LISN, and the measurement port is connected to the measuring instrument. LISNs are used in both compliance and precompliance testing, so conducted precompliance results made using LISNs are often a very good predictor of compliance measurement results.

6.2 Antennas

Radiated compliance testing requires antennas to measure the signals emitted by the equipment under test. Note that radiated compliance testing is always done in the so-called “far field,” with the antenna placed several meters or more from the EUT. Because of the wide frequency ranges required by most radiated testing standards, typically a 1 GHz or more, broadband antennas or a combination of antennas are needed to efficiently cover the entire frequency range. Some common examples of these types of antennas are log-periodic antennas or biconical antennas, such as the one shown in Figure 15.

Figure 15 - Biconical antenna used in EMI testing

Well-designed and properly configured antennas allow for very precise measurements as well as for frequency compensation using antennas factors. The same types of antennas can be used in both compliance and precompliance, but recall that the distances between the antenna and EUT are often shorter in precompliance testing, requiring modifications to the radiated limit lines. With regard to troubleshooting or debugging the causes of emissions, these types of antennas are however not very appropriate: they are normally too large and too bulky to provide precise information about which part or component of the EUT is generating non-compliant emissions.

6.3 Near field probes

Near field probes work in the "near field," that is, in close physical proximity to the source of an emission. There are mathematical definitions of “near field,” but as a practical matter, the “near field” in EMI debugging is usually on the order of a few centimeters. Because of their small size and the ability to physically position them close to the source, near field probes have high spatial resolution, that is, they can often be used to very precisely locate the source of an emission, for example, a pin on a chip or a trace on a printed circuit board. This is very helpful in EMI debugging as it provides information on the physical source of an offending signal. On the other hand, near field probes only support relative measurements: they can be used to find sources of emissions, but cannot be used to make accurate level measurements for the purpose of verifying limits.

Figure 16 - Near field probes

Near field probes can be divided into two main types: H-field probes react to the magnetic near field and often have a loop-type shape. E-field probes, on the other hand, react to the electrical field. In most cases, commercial near field probes come as a kit that contains both types of probes. Note that the signals picked up by near field probes can be quite small, so unless they are connected to a low-noise oscilloscope, a preamplifier may be required.

6.4 Software

Specialized software is commonly used in precompliance testing. The primarily motivation in using software is scripting or automating tests, whereby a program communicates with or controls multiple instruments and accessories through a single user interface. Another important function of software in precompliance testing is collecting and displaying the measured data. Compared to the way that data is presented on individual instruments, precompliance software packages normally can provide a more sophisticated display with advanced options, such as customized limit lines. A software package can also easily incorporate antenna factors, cable loss, etc. into the measurement results. In addition, the ability to generate customized reports or export data is a standard feature in most precompliance software packages. Finally, and perhaps most importantly, software provides higher speed and better repeatability than manual operation, allowing rapid and accurate precompliance testing to be performed even by users who are relatively new to precompliance testing.

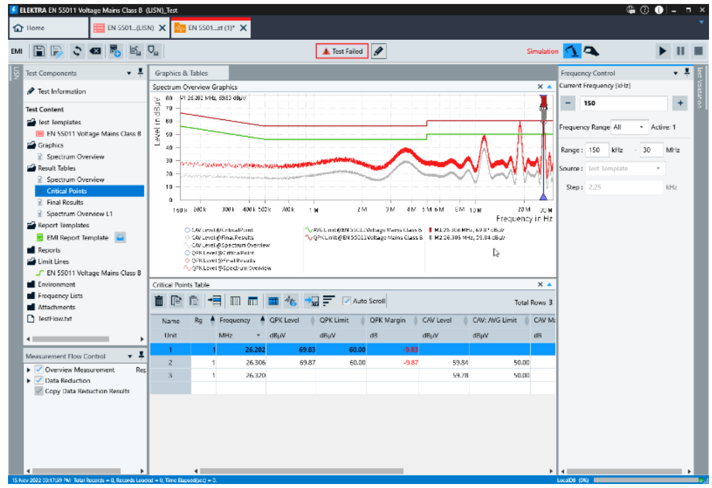

Figure 17 - EMC precompliance software

7 Summary

Most electrical and electronic devices must be tested by third-party labs to ensure that these devices comply to the relevant conducted and radiated emissions standards. The failure rate in compliance tests is often quite high, requiring costly and time-consuming redesign. Precompliance testing is in-house testing done before compliance testing, and is used to identify problems early in the product cycle, where they can be corrected more quickly and more cheaply. Using the correct tools and techniques in precompliance testing both increases the chances of passing the full compliance tests as well as saves significant time and money.

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